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Procedia Engineering 152 (2016) 270 – 275
Procedia Engineering
www.elsevier.com/locate/procedia

International Conference on Oil and Gas Engineering, OGE 2016

Theoretical analysis of changing gas dynamic characteristics of the dust filter with a short diffuser while in operation

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Abstract

The results of the experimental and numerical studies of the dust filter with a short diffuser at various size of a filter element clogging are given in the paper. The connection between the value of the filter clogging and the growth of hydraulic losses in a flowing part of the filter is found, the emergence of this effect from the point of view of redistribution of velocities and vortex formation of a stream is proved. Satisfactory agreement between the calculated and the experimental results is obtained.

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Keywords: analysis; gas dynamic characteristics; short diffuser; filter; velocity profile; pressure losses

1. Introduction

One of the operation features of a short diffuser with a big expansion angle (from 60º and above) is an expressed core of local velocities, observed at the diffuser outlet in the area which is a direct projection of the diffuser inlet [1]. At the same time, the alignment of the velocity profile occurs at the considerable distance from the outlet section of the diffuser.

Short diffusers have been widely used in design of various devices including air filters in life support systems [2]. It is explained by the intention to keep compactness of a design upon transition from the smaller section of the air duct to the larger section of the filter and vice versa. However, the use of a short diffuser in a filter design, apparently, will lead to a non-uniform distribution of a stream along the operating surface of a filter element [3]. As a result, there is an assumption that such character of air stream in a short diffuser can result in the deterioration of operation characteristics of the filter, for example, increasing hydraulic losses because of the premature clogging of the central area of the filter element and the stream overflowing to the peripheral area which is gradually filled, too. It can become the reason of a filter element replacement before the expiry of its life as filter pressure losses will become higher than admissible values.

Nowadays, there is a number of works on studying the flowing of gaseous fluids in the flowing part of short diffusers [4-6]. However, there are no researches analyzing the “short diffuser – filter” system. There are only recommendations concerning the replacement of a filter element for a new one when filter admissible pressure losses are exceeded without considering the condition of the filter element itself [7]. Thus, the task of assessing the influence of a short diffuser design on gas dynamic parameters of the filter seems to be up-to-date. The solution of this task demands carrying out numerical and experimental studies with the purpose of receiving an overview of the air stream in the flowing part of the filter and taking down its gas dynamic characteristics.

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Peer-review under responsibility of the Omsk State Technical University
doi:10.1016/j.proeng.2016.07.702

2. Study subject

Study subject is the air stream velocity field profile in the flowing part of the filter with a short diffuser as well as pressure losses on this filter. Let us describe the process as a whole and the parameters of the study subject. The stream moves along the air duct which length L is 300 mm and diameter d is 112 mm, from there it gets to the flowing part of the filter consisting of a body, an insert imitating a filter element, a short diffuser and a confusor (Fig. 1). The stream leaves the flowing part of the filter via the output pipeline which length m is 100 mm. The body has a rectangular form with section BxH being 320x320 mm; a diffuser and a confusor with length l being 68 mm are conic, with the largest diameter D being 280 mm. The insert is a cloth made from filtering material fixed on a frame and installed crossly in the body at the distance c = 50 mm from the output section of the diffuser and at the distance e = 430 mm from the inflow section of the confusor. Clogging of a filter element is imitated by the placement of a slip with blocked permeability (where foam rubber thickness d is 20 mm) on the cloth surface. The slip is placed coaxially to the diffuser inlet. When carrying out research three options are considered: without a slip and with a slip having diameter D_1, equal to 112 and 280 mm. When carrying out numerical researches the filter element is modelled by the equivalent punched partition, and clogging of a filter element is modelled by decreasing the size of openings in the area limited by the corresponding diameter. The profile of the velocity field is considered in the output section of a short diffuser (section a-a), as well as immediately behind the insert (the equivalent partition) (section b-b). Pressure losses are considered for the whole filter.

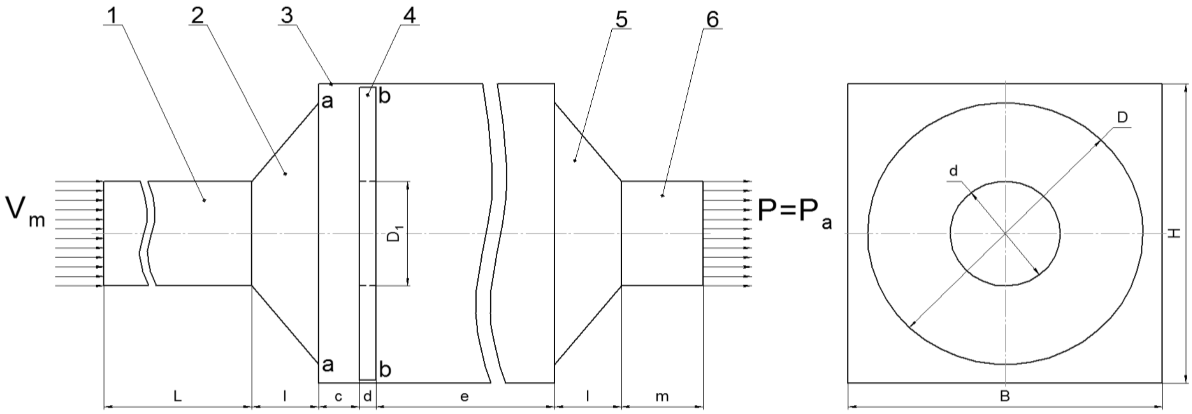

Fig. 1. Scheme of the study subject: 1 - air duct; 2 - short diffuser; 3 - body; 4 - equivalent partition; 5 - confusor; 6 – outlet pipeline.

3. Methods

3.1. Experimental method

For carrying out the experimental studies the stand (Fig. 2) having geometry and the structure similar to the numerical model, was developed and designed. The method of the experimental study includes the definition of the velocity field profile in the output section of a short diffuser and behind an insert, and pressure losses on the filter.

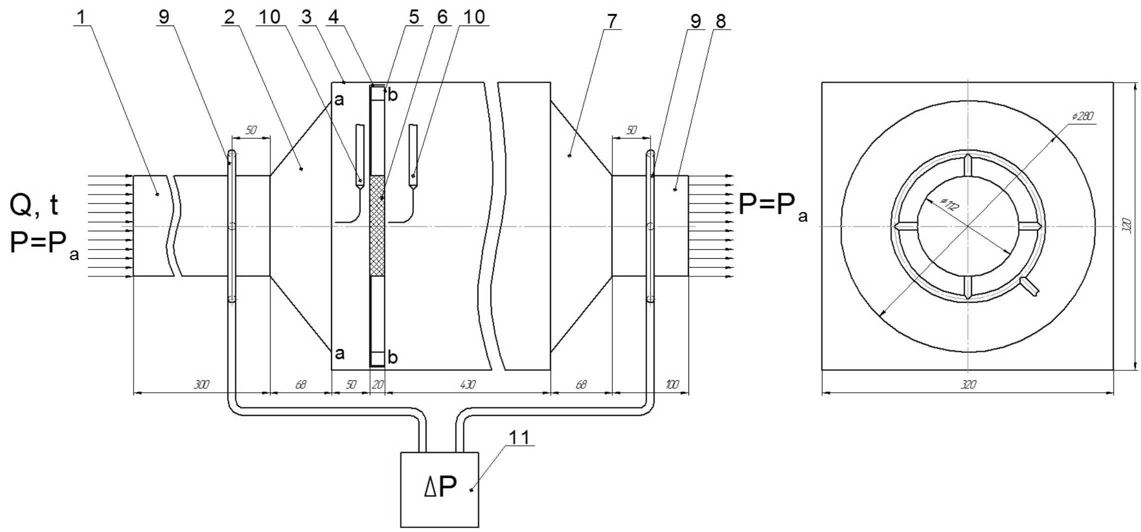

Fig. 2. The experimental stand for carrying out gas dynamic research of the filter: 1 - air duct; 2 - short diffuser; 3 - housing; 4 - cloth from a filtering material; 5 - frame; 6 - slip; 7 - confusor; 8 - output pipeline; 9 - device averaging the pressure; 10 – total-head (Pitot) tube; 11 - digital differential pressure manometer.

In the air duct the air stream at atmospheric pressure and temperature 22 °C with a volume flow 100 m^3/hour is supplied. A digital differential pressure manometer, one end of which is connected to a tube of the total pressure while another is connected to the atmosphere, the pressure drop is measured in the corresponding point of sections a-a and b-b. Then, according to the measured pressure drop, the stream velocity in the corresponding point is calculated. The velocity profile is made up on the basis of calculations results for the central point which is located on the axial line of the filter, and the average values received for each of radiuses where measurements were taken (20, 40, 60..., 160 mm).

Pressure losses on the filter are defined under the same conditions as the velocity profile. The measurement is carried out by a digital differential pressure manometer one end of which is connected to the device averaging the pressure in front of the filter, while another end - to the device averaging the pressure after the filter. The description of the velocity field profile and pressure losses is carried out for each of three options of the insert.

3.2. Methodology of numerical research

Numerical research is carried out in ANSYS CFX package on the basis of the developed and constructed three-dimensional model of the study subject presented in figure 1. The calculation includes the following stages: import of the geometrical model; splitting the model into a network of finite elements; defining of initial and boundary conditions; calculation; viewing and analysis of the obtained results [8]. An entry boundary condition is the average flow rate V_m calculated on the basis of the experimental data. An output boundary condition is the pressure equal to atmospheric $P = P_a$. A working body is air with temperature 22 °C; the flow is isothermal; the turbulence model is SST. The determination of the velocity field profile and pressure losses, as well as in the case of the pilot study, is carried out for each of three options of the equivalent partition.

4. Results and discussion

The main results of numerical and theoretical research are presented in figures 3-7.

The analysis of the received results has shown that when passing air through the flowing part of a short diffuser the major part of a stream gets on the central part of the filtering surface (Fig. 3) which is a direct projection of the diffuser inlet that can lead to its earlier clogging in comparison with peripheral areas. This, in its turn, leads to the redistribution of a stream from the central part of the filter to the peripheral one (Fig. 4-5). It is expressed in decreasing to its minimum values the velocity of the stream outgoing immediately after a slip, that is well noticeable by the velocity fields and their profiles. At the same time, the velocity considerably increases in the area not covered with a slip. Notably, while decreasing of a flow section in the central part of a filter element the absolute speed of air both in the vortex formation area before a filter element and in the flowing part of the filter element itself increases, and that leads to the essential increase in hydraulic resistance of the filter. When analyzing the diagram of pressure losses (Fig. 6), it is possible to note that they grow with increasing in diameter of the area of the filter element closed by a slip. It can be explained by the power loss of a stream at collision with a barrier in the form of a slip when it is forced to change the trajectory to pass through the peripheral area with a minimum resistance which is not observed in the case of a clear surface of a filter element, and also by the intensive vortex formation in the diffuser and before the insert (Fig. 7).

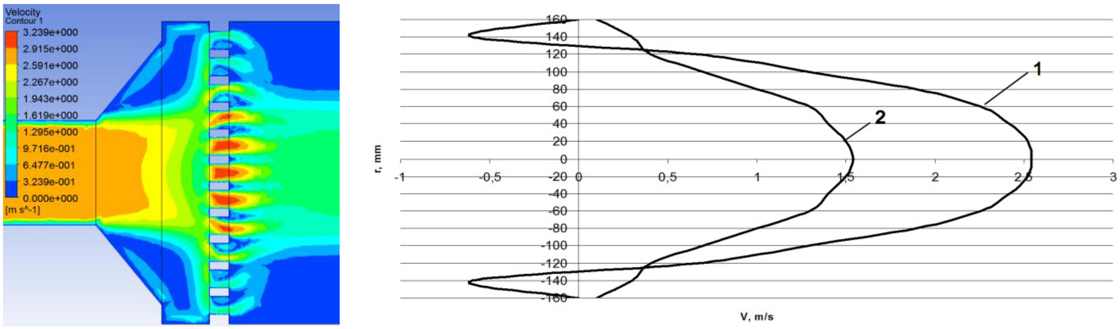

Fig. 3. Velocity field (CFX, on the left) and velocity field profile (experiment, on the right), received without a slip: 1 - output section of a short diffuser; 2 – insert outlet.

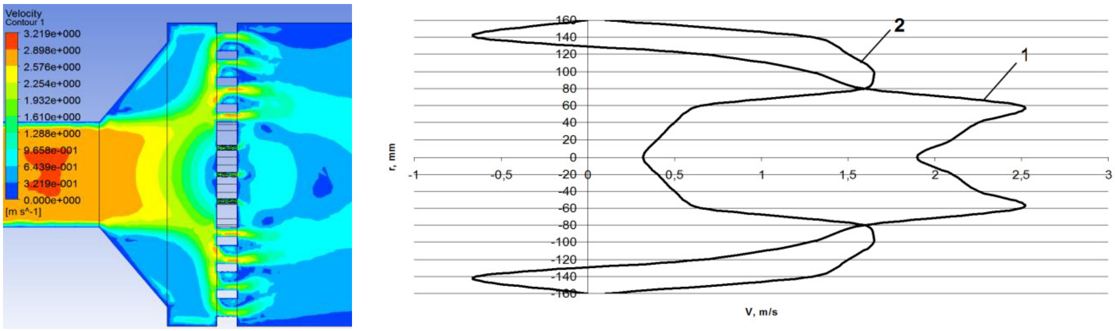

Fig. 4. Velocity field (CFX, on the left) and velocity field profile (experiment, on the right), received with a slip with a diameter 112 mm: 1 - output section of a short diffuser; 2 - insert outlet.

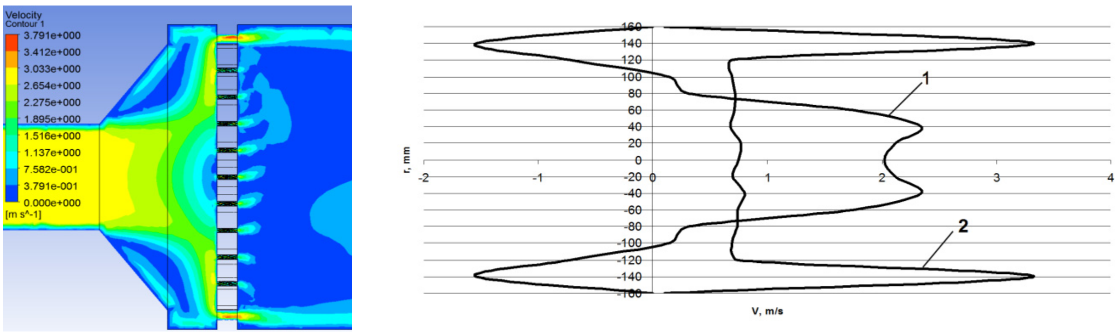

Fig. 5 Velocity field (CFX, on the left) and velocity field profile (experiment, on the right), received with a slip with a diameter 280 mm: 1 - output section of a short diffuser; 2 - insert outlet.

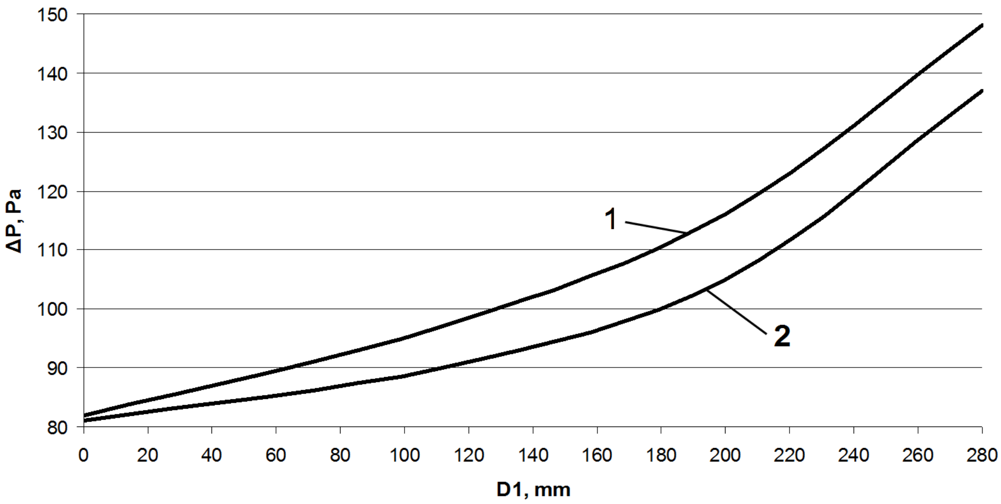

Fig. 6. Dependence of pressure losses on the filter on the slip diameter: 1 - CFX; 2 - experiment.

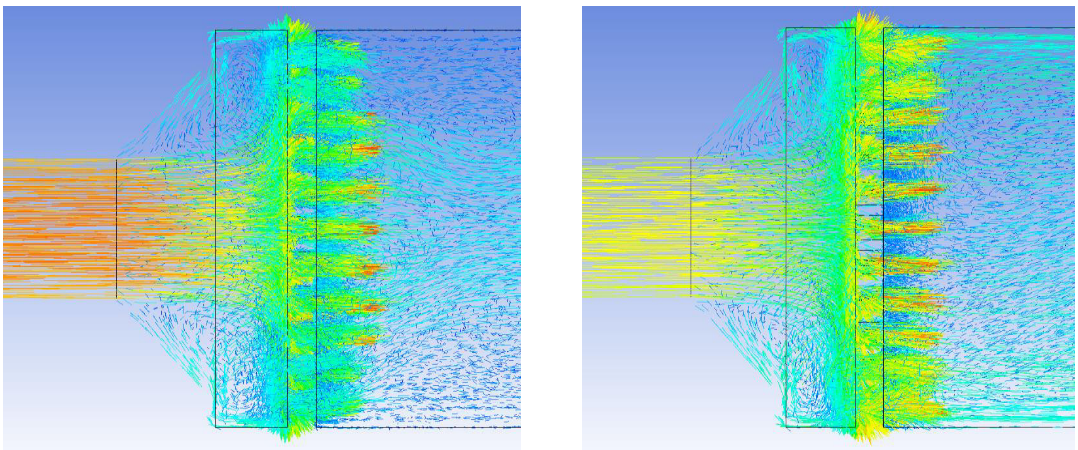

Fig. 7. Vector velocity field in a flowing part of the filter received for a slip with a diameter 112 mm (on the left) and 280 mm (on the right).

When comparing the received experimental and calculated results of the research, it is possible to note their similar character that speaks well for the reliability of the obtained data.

5. Conclusion

Thus, according to the results of the numerical and experimental studies, it is possible to draw a conclusion that the application of a short diffuser with a larger expansion angle in the filter design leads to premature clogging of the central area of a gauze element because of higher flow rate in this area. Further, it leads to the redistribution of a stream to the peripheral area of a gauze element which can become a reason for the growth of hydraulic losses in the filter and increasing the power spent by the air circulation fan in a life support system [9].

Acknowledgements

Applied scientific researches and the experimental developments are carried out with financial support of the state represented by the Ministry of Education and Science of the Russian Federation. Unique identifier of applied scientific researches is RFMEFI57715X0203.

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